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The Development of a Broad Band Sound Absorber using Materials from the Biomass

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ABSTRACT

Efficient broad band sound absorbers are frequently very complex systems. For example, those employed in broadcast studios can consist of a panel or membrane absorber with a large air space behind a thick layer of porous absorber such as rock wool. In this paper we propose an alternative solution based upon the use of biomass materials that have the advantage of being sustainable. The key to these solutions lies with the acoustical properties of reed configurations. Two configurations are investigated by means of measurements in a reverberation chamber. The first configuration involves short lengths of reed (typically 15cm long) arranged so that their longitudinal axis is perpendicular to the backing wall. These are again shown to provide good broadband sound absorption. Measurements made using an impedance tube suggest that the absorption mechanism is similar to that of a quarter wave absorber. The second involves long reeds aligned in parallel with their longitudinal axes parallel to the backing wall. These are shown to provide good low frequency performance for practical thicknesses. It is then demonstrated that the high frequency performance can be enhanced by the use of other biomass materials such as flax or hemp.

1. INTRODUCTION

In some circumstances, such as in broadcast studios, a considerable amount of sound absorption is required over the entire audio frequency range and the limited area available for the application of treatment results in the use of composite absorbers [1]. Typically fibrous materials such as mineral wool provide high frequency absorption and other systems, notably panels over air spaces, provide low frequency absorption. Thus combined absorbers typically consist of a limp panel over an air space covered with a thick layer of porous absorber. The depth of such treatment can be considerable. In this paper we propose an alternative solution based upon the use of biomass materials that have the advantage of being sustainable. The term biomass refers to living and recently dead biological material. Biomass materials are inherently sustainable as they constitute part of the normal carbon and nitrogen cycles. Thus, provided only renewable energy is employed during processing, they are virtually carbon neutral. Similarly, if the use of highly toxic chemicals for protection against deterioration due to biological attack from fungi or insects is avoided then they can be disposed of after use by returning to the natural cycles by simple composting.

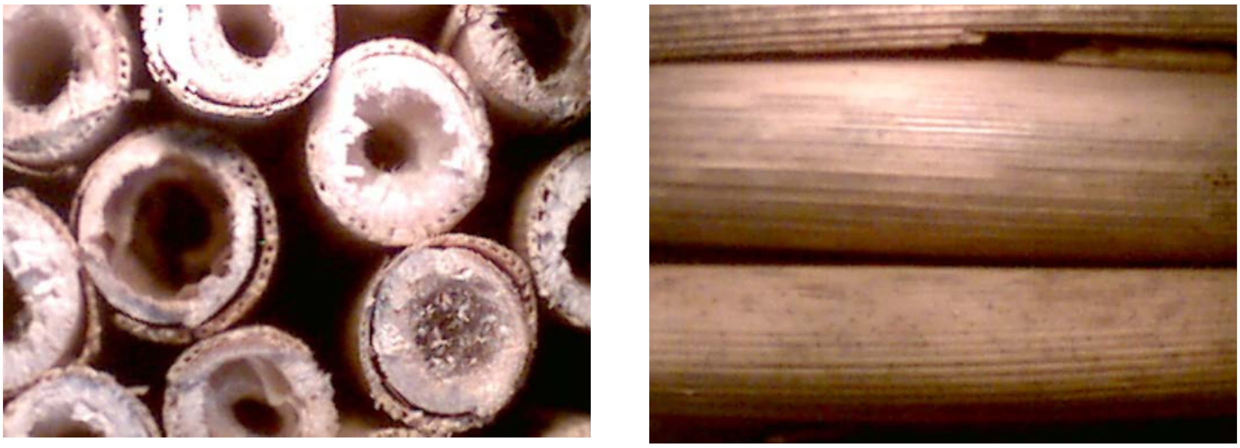
2. MEASUREMENT SYSTEMS

Acoustic measurements of an absorbent material can be carried out in a laboratory using the impedance tube or reverberation chamber methods. The impedance tube was employed in this work for measurements on small samples. The measurements presented in this paper were made on 50mm thick samples of materials using the Brüel & Kjær Impedance Tube Kit Type 4206. Tube measurements were based on the two-microphone transfer-function method described in ISO 10534-2 [2].

The reverberation chamber was employed to measure the absorption properties of heterogeneous materials. The reverberation chamber at the Acoustics Research Unit at the University of Liverpool measures 5m x 5m x 4.8m and thus has a volume of 120m3. EN 20354 [3] specifies a minimum volume of 150 m3 and therefore the Liverpool facility does not satisfy this requirement. However, in practice it is sufficiently close to the recommended value that measurements will be accurate apart from at the very lowest frequencies. Other measurements were made using the reverberation chamber at EMPA, Zurich, which complies fully with the standard.

3. ACOUSTAL ABSORPTION OF REED CONFIGURATIONS

Previous work by the authors has identified the potential of reeds as sustainable sound absorbers. Two basic configurations have been studied, The first was the end on configuration in which the cut ends of the material are perpendicular to the incident sound, as shown in Figure 1a. The “end-on” structure consists of blind (i.e. with a closed end) reed tubes with large prismatic voids between them. The tubes are hollow with a small internal diameter and it is to be expected that there will be dissipative losses as sound propagates in these tubes. The tubes also contain pith which might be expected to contribute to the sound absorption. However, as the holes in the reed are blind and although they might be expected to make a significant contribution to the sound absorption, it is not clear how they might affect the effective bulk flow resistivity.



(a) (b)

Figure 1: (a) Showing cut ends of reeds; (b) Showing gaps between aligned reeds

The second configuration examined was the transverse configuration in which the reed stems are perpendicular to the incident sound as shown in Figure 1b. Because of the irregular nature of the reed cylinder there are slit like gaps between reeds as can be seen in Figure 1b and these will link through to the large voids between reeds that are visible in Figure 1a.

Figure 2 shows the measured absorption coefficient of a 50mm long bundle of reed with reeds of lengths 8.5cm, 10cm and 15cm as a function of frequency for the “end on” configuration. Well defined peak values of absorption coefficient can be seen along with equally well defined troughs at approximately 3,150Hz. For each sample the reed lengths corresponds to approximately a quarter wavelength at the frequencies of peak absorption and a half wavelength at the frequencies where there is an absorption minimum min. Thus it may be surmised that the observed characteristics are affected by resonance effects.

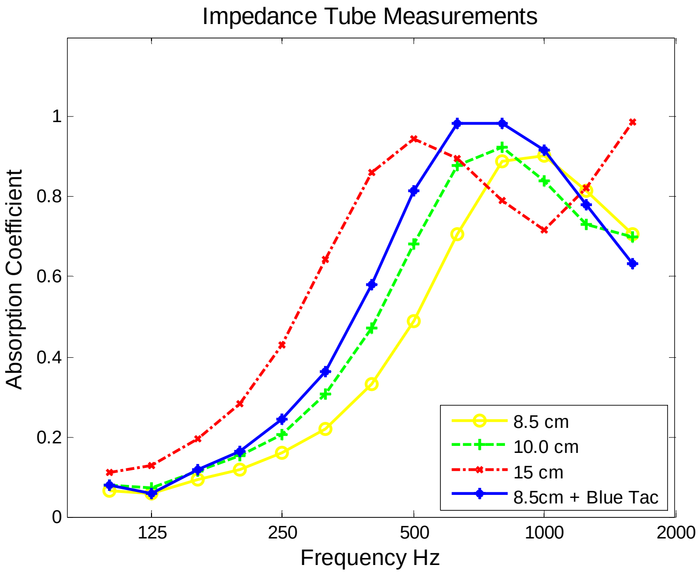


Figure 2: Absorption Characteristics of End-on Reeds Bundles of Different Lengths

As the frequency at which the absorption peak corresponded to the reed length is equal approximately one quarter wavelength it would appear that either the hollow reed or the cavity between reeds was acting as a quarter wave resonator. The hollow ends of the 8.5 cm reeds, therefore, were sealed off with putty and the measurements repeated. The results are also shown in Figure 2. It can be seen that the effect of sealing the reeds is to increase the absorption coefficient at most frequencies and to lower the peak frequency slightly. It can thus be concluded that the narrow space between the reed stems is the most important aspect of this configuration.

Measurements of these reed configurations were only made with the larger tube of the Impedance tube measuring system as some the size of the reed stems (typically around 5cm in diameter) was such that there was potentially considerable variation in the porous nature of different samples when used with the 29mm diameter tube. It should be noted that obtaining consistent results from impedance tube measurements with samples of reed and straw proved difficult for two reasons. The first was the need to seal the sample edges very carefully. If this was not done then odd additional peaks and troughs were observed in the measured absorption characteristics. Secondly, there was considerable variability between different lengths of reeds or straw such that if two different but nominally identical samples were prepared the pore structure could be very different. Nevertheless, the results do demonstrate the potential of reeds and straw layers as porous absorbers and suggest that measurements on larger samples in a reverberation chamber would be valuable.

Figure 3 shows the results of measurements made with 12 m2 of reeds cut to an approximate length of 14cm. It can be seen that this reed configuration was very effective at absorbing sound at frequencies above 250Hz. The expected peak at around 600Hz, the frequency for which 14cm corresponds to the quarter wavelength, cannot be observed. This is probably due to the slight variations in the lengths of the reed stems leading to a broadening of the frequency response.

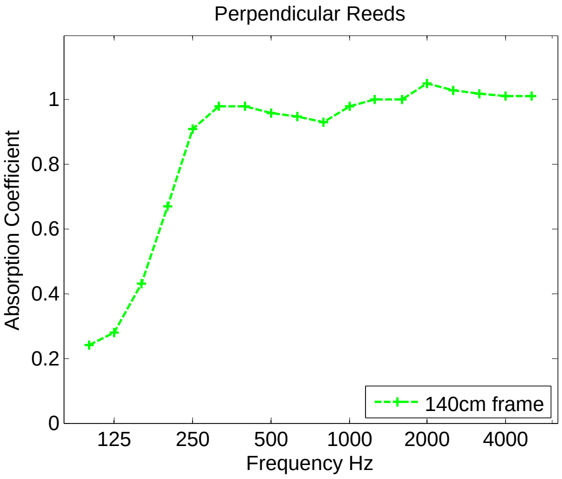


Figure 3: Absorption Characteristics of End-on Straw and Reed Bundles Measured in Reverberation Room.

The measured values of the absorption coefficient as a function of frequency for layers of reeds and straw perpendicular to the incident sound field as measured in the impedance tube are shown in Figure 4. Measurements of these reed configurations were again only made with the larger tube of the Impedance tube measuring system as there was potentially considerable variation in the porous nature of different samples when used with the 29mm diameter tube.

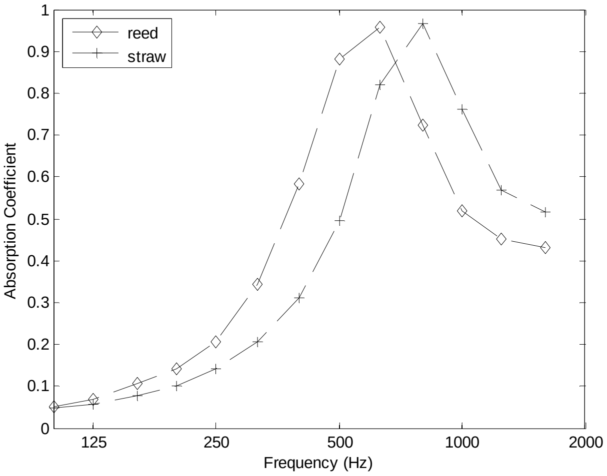


Figure 4: Absorption Characteristics of Straw and Reed Bundles Aligned Perpendicular to the Incident Sound

It can be seen that the values of absorption coefficient are small at low frequencies and although they rise with increasing frequency, they exhibit significant peaks and this characteristic is typical of a material having a heterogeneous pore structure. The results show a pronounced peak in the characteristics at 630 Hz for reeds and 800Hz for straw. This is probably due to the difference in the typical tube diameters of reeds and straw.

The impedance tube measurements have indicated that reeds have some potential for application to a noise barrier. However, the small samples employed in the impedance tube cannot be assumed to accurately replicate the pore structure to be found in large mats and hence reverberation room measurements were essential. The results obtained for reed thicknesses of 35mm, 50mm, 100mm and 150mm are shown in Figure 5. The thicknesses were built up with layers of 5cm thick reed mats and a 3.5cm thick reed roll. The double and triple layers of mats were both arranged with all mats aligned in the same direction as not only does this configuration seem to give a slightly better performance but it is probably the most practicable for manufacturing purposes.

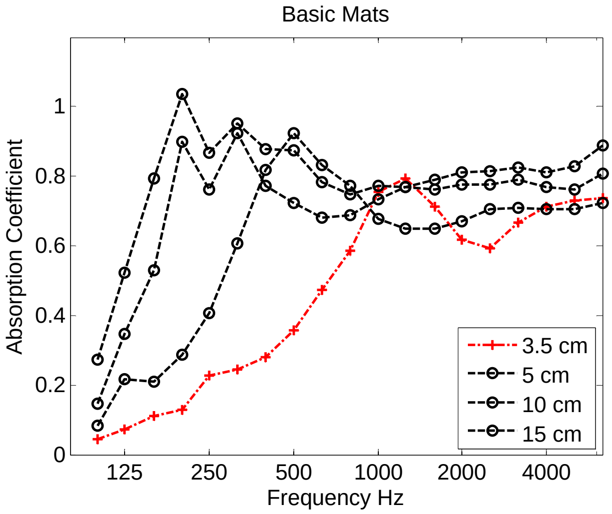


Figure 5: Absorption Characteristics of Aligned Reeds of Different Thickness Measured in Reverberation Room

At low frequencies it can be seen that the effect of increasing the thickness of the reed layer is to move the frequency at which the absorption coefficient peaks downwards and to introduce additional peaks. There is a slight increase in the low frequency absorption coefficient for the 150mm thick configuration. At high frequencies there is a slight increase in the absorption coefficient with increasing layer thickness. The increase is greater for an increase from 50mm thick to 100mm thick than for an increase from 100mm thick to 150mm thick. It is probable that there would be an additional increase if the thickness were to be made larger but this would small.

3. FIBROUS ABSORBERS FROM THE BIOMASS

Although the low frequency performance of the 5, 10 and 15cm reed layers is good the absorption coefficient at high frequencies is too low when compared with existing systems. A solution to this problem would be to place a high frequency porous absorber above the reeds. The porous absorber will absorb high frequency sound whilst allowing low frequency sound to penetrate to the reed layer.

The absorption coefficient of a fibrous absorber mounted against a solid backing is determined by its thickness and flow resistivity [4]. A number of methods have been developed for predicting flow resistivity from other material properties. For example, one expression reported by Mechel [5] is as follows:

$$\sigma = \frac{6.8\eta(1-\varepsilon)^{1.296}}{a^2\varepsilon^3} \tag{1}$$

Where η is the viscosity of air (equal to 1.84 x 10-5 poiseuille), a is the radius of the fibres and ε is the porosity which is the volume fraction occupied by pores in the material. Equation 1 relates to fibre radii ranging from 20 to 30 μm.

For a material having only a small amount of binder and assuming the presence of no closed cells, the porosity, ε, is given by:

$$\varepsilon = 1 - \rho B/\rho m \tag{2}$$

Bies and Hansen [6] have presented the following expression which relates the flow resistivity to the bulk density, ρ, of the porous absorber for fibre glass and mineral fibres:

$$\sigma = \frac{3.18\times10^{-9}}{4a^2\rho^{-1.53}} \tag{3}$$

From examination of Equations 1 and 3 it is apparent that the factors that determine the absorption characteristics of fibrous absorbers are the fibre diameters and the porosity. The latter is a function of the degree to which the material is consolidated or compacted. In this work a variety of natural fibres were obtained and a systematic investigation of their absorptive properties was carried out.

There are a number potential biomass candidate materials in the form of organic fibres, either vegetable or animal in origin. Many of these have a long history of use in fabrics (cotton, wool, flax, silk), as floor coverings (wool, reeds), sacking (jute, hessian) and ropes (hemp) [7].

Table 1 contains a summary of the sample materials examined. It can be seen that the plant based materials have very similar densities as they consist of the same basic principal components, cellulose, hemi-cellulose and lignin. Variations in the densities are due to different proportions of these components as their densities vary with values of 1397 and 1559 and 1520 kg/m3 being reported for lignin, hemicellulose and cellulose respectively [8] . Thus, the lower values of density for hemp and sisal result from a greater proportion of lignin than in other fibres.

The bulk density of the samples for the large tube was measured and the small tube samples were made to the same bulk density. Micrographs of the fibres were made and the mean fibre diameter was measured from the micrographs (only a small sample size, typically three or four fibres). Samples of the lighter coloured materials were dyed prior to preparing micrographs to aid visibility. The density of the matrix material was obtained from published literature allowing the porosity of the samples to be calculated. The results of these measurements are summarised in Table 1.

Measurements were made of all samples using the impedance tube method. The samples were hand compacted in the tube sample holder to give a sample thickness of 50mm. Micrographs were taken of each sample and used with a calibration graticule to obtain information regarding the fibre diameters.

Substance	Fibre diameter (m)		Density (Kgm-3)		Porosity
	mean	standard deviation	Matrix material	Bulk sample	
Hemp batts	9.39E-05	3.48E-05	1.48E+03	7.59E+01	9.49E-01
Hemp mats	7.70E-05	7.07E-06	1.48E+03	1.00E+02	9.33E-01
Hemp fibre	1.68E-04	1.16E-04	1.48E+03	8.84E+01	9.40E-01
Flax fibre	2.18E-05	2.05E-05	1.50E+03	7.84E+01	9.48E-01
Raw cotton	1.35E-05	8.96E-07	1.53E+03	4.05E+01	9.73E-01
Sisal fibre	2.13E-04	6.14E-05	1.41E+03	3.86E+01	9.73E-01
Ramie ‘tops’ fibre	2.44E-05	1.21E-05	1.50E+03	9.61E+01	9.36E-01
Jute raw fibre	8.12E-05	3.70E-05	1.37E+03	6.56E+01	9.52E-01
Jute carded fibre	6.21E-05	1.74E-05	1.37E+03	4.91E+01	9.64E-01
Bamboo fibre	1.21E-05	9.91E-07	1.32E+3	5.81E+01	9.56E-01
Soya fibre	1.19E-05	2.32E-06	1.29E+03	4.67E+01	9.64E-01
Tencel	1.47E-05	1.56E-06	1.53E+03	1.13E+02	9.26E-01
Raw wool	3.71E-05	9.09E-06	1.30E+03	1.98E+01	9.85E-01
Wool batts	6.30E-05	1.58E-05	1.30E+03	2.57E+01	9.80E-01

Table 1 Physical properties of fibre samples

Figure 6 shows the measured absorption coefficient as a function of frequency for cotton, soya, wool and sisal, each having a thickness of 50mm. It can be seen that the cotton and soya fibres have absorption properties which are similar to those of rock wool or fibre glass of the same thickness but that the wool and sisal fibres are much less effective. This is probably due to the nature of the fibres of each material. The cotton and soya fibres are both very fine with average diameters of 14 and 12 microns respectively and are easily compressed. The wool and sisal fibres are coarser with average diameters of 37 and 213 microns respectively. The wool fibres also have a natural “springiness” which makes compression of the materials much more difficult resulting in greater porosity. Thus, the measurements indicate that a reasonably well compressed material with a small fibre diameter would be the best option.

There are advantages for the manufacture of combined absorbers in using material available in standard sizes. For example, the reeds are available bound into squares of side lengths 1m. A number of natural fibres are marketed in the form of batts for use as thermal insulation. One such material is hemp which is a coarse bast fibre with very long fibre lengths hence its use in ropes and twine.

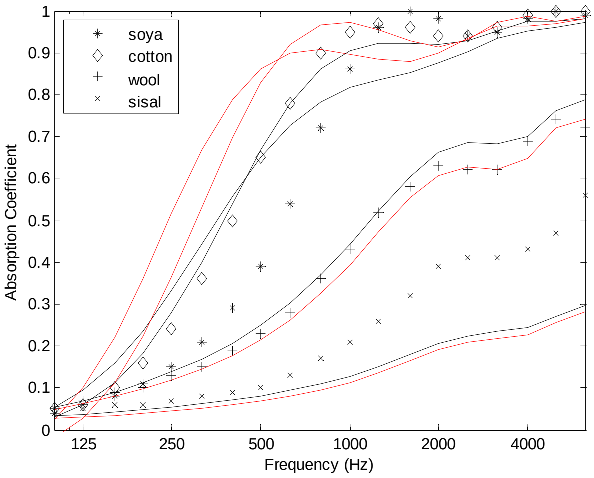


Figure 6: Measured Absorption Coefficient of soya silk, raw cotton, raw wool and sisal.

Hemp was available in the form of hemp mats and hemp batts. The hemp batts were 85% hemp fibres bound into a 'batt' with a 15% polyester binder. The polyester appears to be in the form of fibres mixed in with the hemp then heated to fuse the batt together. The polyester fibres were ignored for the purposes of estimating the fibre size although they could be seen on the micrograph.

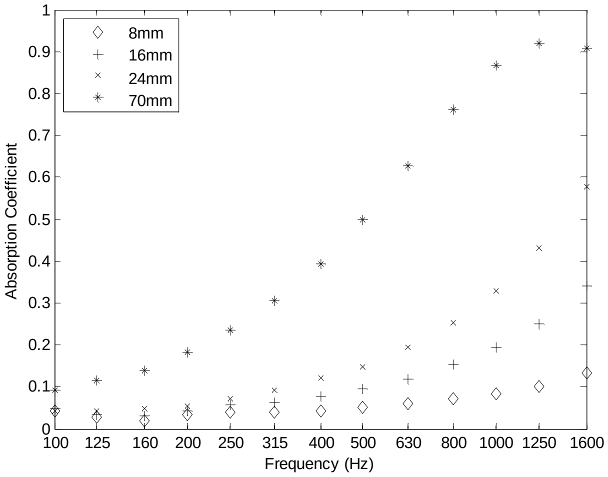


Figure 7: Absorption Coefficient of Hemp mats and Hemp Batts

Figure 7 shows the measured absorption characteristics for the hemp samples. It can be seen that the performance for the densely compacted mats is poor even at the high frequencies whilst the relatively less compacted batt shows characteristics typical of conventional mineral wool batts. The god high frequency performance of the hemp batts makes them very suitable for use in a combined absorber along with the reed mats.

THE COMPOSITE ABSORBER

The results of the previous sections have shown that fibrous absorbers can be used as the basis of high frequency absorption and that highly heterogeneous porous materials in the form of aligned reeds can provide very good low frequency and moderate medium and high frequency sound absorption. This reflects the situation with conventional sound absorbers where fibrous materials such as mineral wool provide high frequency absorption and other systems, notably panels over air spaces, provide low frequency absorption. The performance of the aligned reeds at low frequencies is similar to that of panel absorbers hence the effect of combining reeds and porous absorbers was investigated.

Figure 8 shows the results measured in the reverberation chamber of the absorption coefficients for absorber systems consisting of 5 and 10cm layers of reeds under a 7cm thick hemp batt.

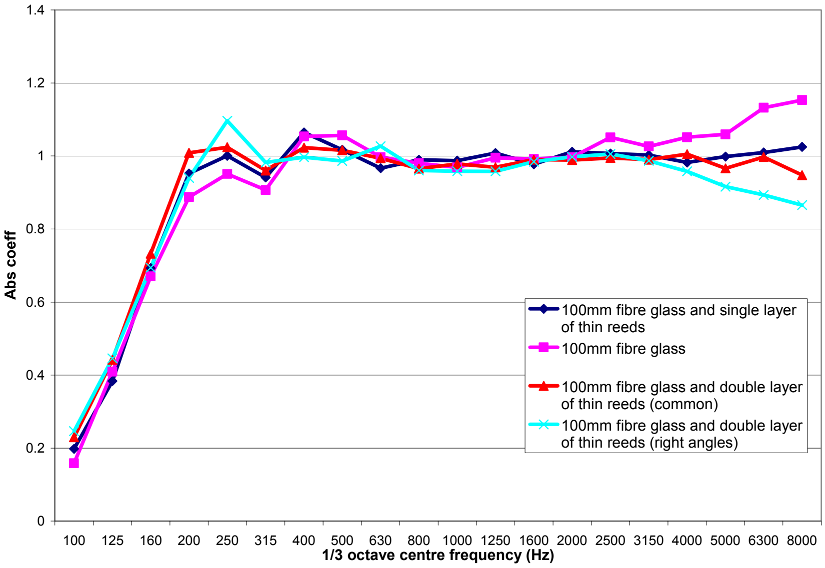


Figure 8: Absorption coefficient of composite systems compared to that of 100mm thick fibre glass: single layer of reed on top of 100mm thick fibre glass; double layer of reed on top of 100mm thick fibre glass with common orientation; double layer of reed on top of 100mm thick fibre glass with transverse orientation.

It can be seen that the good low frequency performance of the reeds, especially for a thickness of 10cm, is maintained but complemented by the good high frequency performance of the hemp. The result is a composite absorber which is relatively shallow but comparable in performance with the very specialised systems employed in broadcast studios [1].

4. CONCLUSIONS

An alternative solution for the manufacture of broadband absorbers has been proposed which is based upon the use of biomass materials that have the advantage of being sustainable. The key to these solutions lies with the acoustical properties of reed configurations. Two configurations are investigated by means of measurements in a reverberation chamber. The first configuration involves short lengths of reed (typically 15cm long) arranged so that their longitudinal axis is perpendicular to the backing wall. These were shown to provide good broadband sound absorption although their performance fell short of that of current systems at the lowest frequencies. Measurements made using an impedance tube suggest that the absorption mechanism of this configuration is similar to that of a quarter wave absorber.

The second involves long reeds aligned in parallel with their longitudinal axes parallel to the backing wall. These are shown to provide good low frequency performance for practical thicknesses. It is then demonstrated that the high frequency performance can be enhanced by the use of other biomass materials such as flax or hemp.

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